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City and County of San Francisco

Public Utilities Commission

HETCH HETCHY WATER AND POWER WATERSHED FIRM YIELD STUDY

SVERDRUP & PARCEL AND ASSOCIATES, INC.
SAN FRANCISCO, CALIFORNIA

AND

BOOKMAN-EDMONSTON ENGINEERING, INC.
SACRAMENTO, CALIFORNIA

IN ASSOCIATION WITH

JORDAN/AVENT AND ASSOCIATES
SAN FRANCISCO, CALIFORNIA

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City and County of San Francisco

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Sverdrup & Parcel and Associates, Inc.
San Francisco, California

and

Bookman-Edmonston Engineering, Inc.
Sacramento, California

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Hetch Hetchy Water and
Power watershed farm
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(Three Separately Bound Volumes)

Appendix to Watershed Firm Yield Study, Hetch Hetchy Water and Power System.

Volume I

Part 1 - Hetch Hetchy Watershed Firm Yield Study, General Description and Results

Part 2 - Hetch Hetchy Watershed Firm Yield Study, Manual Operation Study Explanation

Volume II

Part 3 - Hetch Hetchy Watershed Firm Yield Study, Users Manual for Computer Model of Hetch Hetchy Water and Power System Utilizing HEC-5

Part 4 - Hetch Hetchy Watershed Firm Yield Study, Supporting Data

Volume III

Part 5 - Hetch Hetchy Watershed Firm Yield Study Operation Study for 1921 Through 1978

CHAPTER I - INTRODUCTION

The Hetch Hetchy Water and Power System serves a major portion of the water supply of the San Francisco Bay area including San Francisco, the Peninsula and locations in the East Bay area. Electrical power is also supplied. Certainty of adequate future water supplies is essential to the economy and well-being of the service area. The drought of 1975-77 and greater demands for instream flows in the Tuolumne River have raised concern regarding the earlier estimates of the firm yield of the Hetch Hetchy System.

The Public Utilities Commission engaged Sverdrup & Parcel and Associates, Inc., in association with Bookman-Edmonston Engineering, Inc., Woodward-Clyde Consultants and Jordan/Avent and Associates to undertake a systemwide power and watershed firm yield study. Bookman-Edmonston was responsible for the water yield studies. This report summarizes the studies and findings regarding water supplies. Supporting information is contained in three volumes of appendix material.

Objective

The primary objective of the study was to determine whether the Hetch Hetchy System can produce a firm yield of 400 million gallons per day (mgd), which is the yield expected by San Francisco, and if the yield is less than 400 mgd to identify feasible alternative facilities which could be constructed

to increase the total yield to 400 mgd. A secondary objective was to develop a computer model of the water and power operation of the facilities for use in the requested water and power yield studies and for subsequent operation and management of the facilities.

Scope

The determination of the water yield of the Hetch Hetchy System was based on the capability of existing facilities operated under existing rights and agreements. Operation for water supply was primary with operation for power generation being secondary. These priorities could be expected to prevail during dry years which are critical in safe yield determinations.

Water operations necessary to provide a uniform supply of 400 mgd at the Oakdale Portal of the Hetch Hetchy Aqueduct were determined for the 1928-34 and 1975-77 dry periods by standard "manual" calculation procedures. Concurrent effort was directed toward development of a computer model of the System with which to determine both water and power yields and operating criteria for the 1921-22 to 1977-78 period.

Since the anticipated yield of 400 mgd from existing facilities during historic dry periods was verified, it was not necessary to evaluate alternative projects which could be constructed to bring the yield up to 400 mgd. The firm yield of 400 mgd could be achieved only by sacrificing some power production with existing facilities, however, and conceptual study was given to methods to reduce the impact on power production.

A general purpose river basin computer program developed by the Hydrologic Engineering Center of the Corps of Engineers was adopted for the Tuolumne River Basin. This program, called HEC-5, was made available by the Corps of Engineers through the Boeing Computer Services Company in Seattle, Washington. Assistance was provided by the staff of HEC in use of the HEC-5 and in correcting some problems which were identified through its application to the Hetch Hetchy System. The Hetch Hetchy facilities and downstream Don Pedro Reservoir storage of the Hetch Hetchy System required, in addition to the basic program, special program instructions and some necessary revisions of the existing program were identified. The program and arrangements for its use by Hetch Hetchy management is fully described in the appendix to this report.

Restrictions on recreation use in the Hetch Hetchy Reservoir and its watershed are greater than in Lake Lloyd and Lake Eleanor and their watersheds and, therefore, there is less exposure to waterborne health hazards in the Hetch Hetchy watershed. The amount of storage necessary to produce a full supply of 400 mgd plus 30 mgd for the Moccasin Fish Hatchery solely from the Hetch Hetchy Reservoir was determined. (Note: Subsequent to completion of operation studies, it was learned that the Hatchery requires 30 cubic-feet per second instead of 30 mgd, or about 11,500 acre-feet less than used in the yield studies. This difference amounts to about two percent of the total water demand and the studies were not redone.)

Basic water supply information furnished by the Hetch Hetchy Water and Power staff was used in the studies. These data are based on records of flow reviewed and published by the U. S. Geological Survey and on computations of full natural flow and evaporation made in accordance with procedures agreed upon by Hetch Hetchy Water and Power, the Modesto Irrigation District and the Turlock Irrigation District.

A field inspection of the Hetch Hetchy Facilities was made in the company of staff of the Hetch Hetchy Water and Power at the beginning of the study to obtain a clear understanding of the facilities and their operation. Computational procedures and assumptions were reviewed with the staff during the early study phase and preliminary results were described to the management of Hetch Hetchy Water and Power.

This report summarizes the water yield studies and findings. Details of the studies and computational procedures are presented in an appendix organized as shown in the table of contents. Basic data on streamflows, demands and conveyance capacities used in the yield studies are in cubic-feet per second and the analyses use these units rather than million gallons per day. The objective yield of 400 million gallons per day (mgd) is equivalent to a flow rate of about 620 cubic-feet per second (second-feet or cfs) or 448,000 acre-feet (AF) per year.

CHAPTER II - WATER SUPPLY EVALUATION

Estimates of firm water supplies depend on assumptions regarding future precipitation, agreements and other legal contraints regarding use and sharing of water supplies and the manner of operating water facilities. The conditions which were used in this evaluation of the Tuolumne River Basin are described in this chapter.

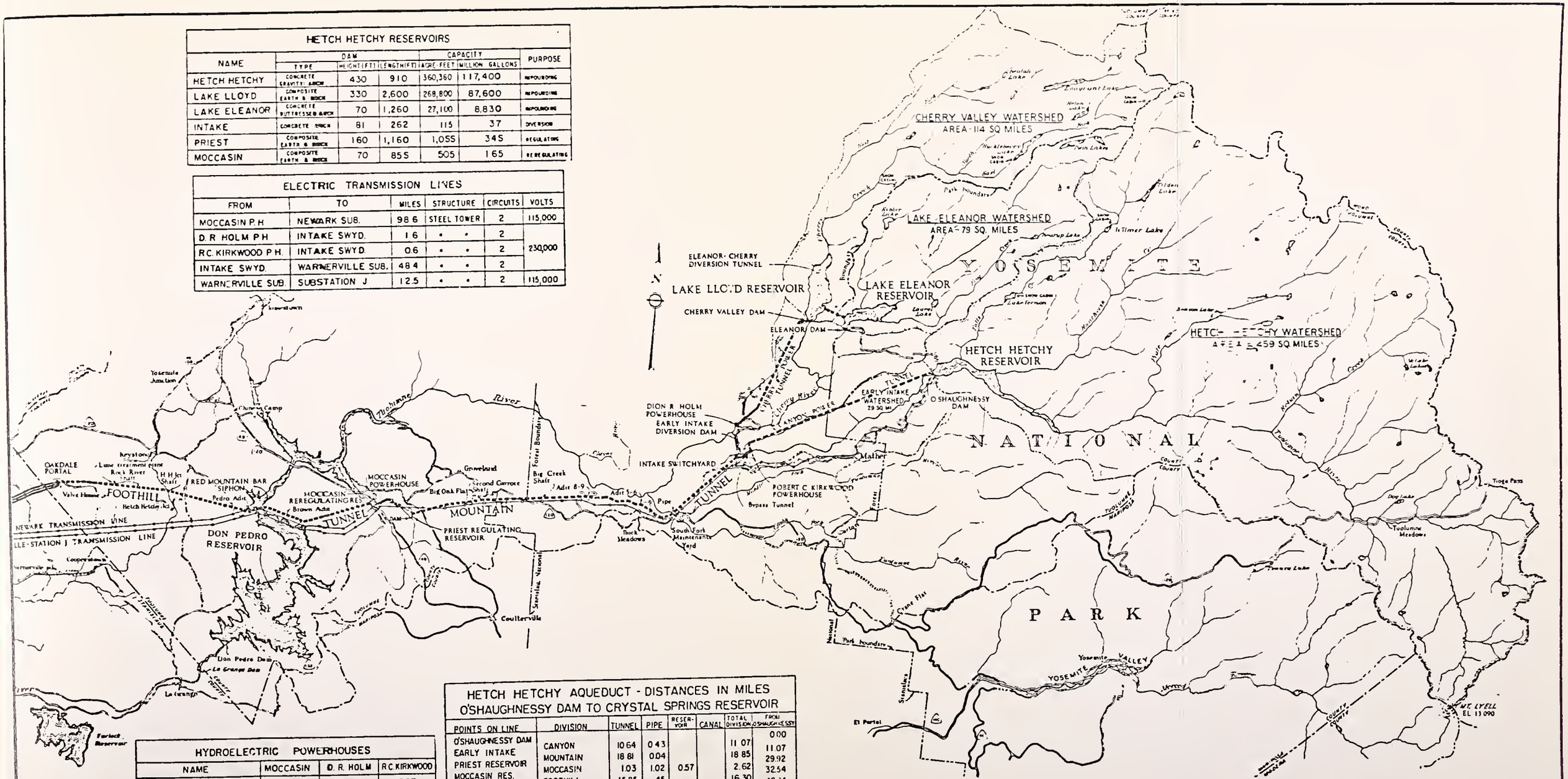
Hetch Hetchy Water and Power System

The facilities of the Hetch Hetchy Water and Power System are shown on Plate 1, "General Map of Hetch Hetchy Water and Power System In 1978". Facilities of concern in this study are "upstream" of the Oakdale Portal on the Foothill Tunnel as described in the following tabulation.

FACILITY	CAPACITY
Hetch Hetchy Reservoir	360,360 acre-feet
Canyon Power Tunnel	1,100 second-feet
Early Intake Reservoir	155 acre-feet
Lake Eleanor Reservoir	27,100 acre-feet
Lake Lloyd Reservoir	268,800 acre-feet
Eleanor-Cherry Diversion Tunnel	1,240 second-feet
Cherry Power Tunnel	830 second-feet
Lower Cherry Aqueduct	250 second-feet
Mountain Tunnel	730 second-feet
Priest Reservoir	1,055 acre-feet
Moccasin Reservoir	505 acre-feet
Foothill Tunnel	620 second-feet

HETCH HETCHY RESERVOIRS						
NAME	DAM TYPE	DAM HEIGHT (FT)	DAM LENGTH (FT)	CAPACITY ACRE-FEET	CAPACITY MILLION GALLONS	PURPOSE
HETCH HETCHY	CONCRETE GRAVITY ARCH	430	910	360,360	117,400	REPOUNDING
LAKE LLOYD	COMPOSITE EARTH & ROCK	330	2,600	268,800	87,600	REPOUNDING
LAKE ELEANOR	CONCRETE BUTTRESSED ARCH	70	1,260	27,100	8,830	REPOUNDING
INTAKE	CONCRETE ARCH	81	262	115	37	DIVERSION
PRIEST	COMPOSITE EARTH & ROCK	160	1,160	1,055	345	REGULATING
MOCCASIN	COMPOSITE EARTH & ROCK	70	855	505	165	REREGULATING

ELECTRIC TRANSMISSION LINES					
FROM	TO	MILES	STRUCTURE	CIRCUITS	VOLTS
MOCCASIN P.H.	NEWARK SUB.	98.6	STEEL TOWER	2	115,000
D. R. HOLM P.H.	INTAKE SWYD.	1.6	• •	2	230,000
R.C. KIRKWOOD P.H.	INTAKE SWYD.	0.6	• •	2	
INTAKE SWYD.	WARNERVILLE SUB.	48.4	• •	2	
WARNERVILLE SUB.	SUBSTATION J	12.5	• •	2	115,000



HYDROELECTRIC POWERHOUSES				
NAME		MOCCASIN	D. R. HOLM	R.C. KIRKWOOD
COMMENCED OPERATION		1969	1960	1967
NUMBER OF UNITS		2	2	2
TURBINES	TYPE	MULTI-JET VERTICAL-IMPULSE	MULTI-JET VERTICAL IMPULSE	MULTI-JET VERTICAL IMPULSE
TURBINES	SPEED-RPM	300	400	327
TURBINES	DESIGN HEAD-FEET	1147	2,230	1,245
TURBINES	RATED PLANT H.P.	143,000	187,000	106,000
GENERATORS	RATED PLANT KVA	100,000	150,000	75,000
GENERATORS	RATED POWER FACTOR	0.90	0.90	0.90
GENERATORS	VOLTAGE-KILOVOLTS	13.8	13.8	13.8

HETCH HETCHY AQUEDUCT - DISTANCES IN MILES O'SHAUGHNESSY DAM TO CRYSTAL SPRINGS RESERVOIR							
POINTS ON LINE	DIVISION	TUNNEL	PIPE	RESERVOIR	CANAL	TOTAL DIVISION	FROM O'SHAUGHNESSY
O'SHAUGHNESSY DAM							0.00
EARLY INTAKE	CANYON	10.64	0.43			11.07	11.07
PRIEST RESERVOIR	MOUNTAIN	18.81	0.04			18.85	29.92
MOCCASIN RES.	MOCCASIN	1.03	1.02	0.57		2.62	32.54
OAKDALE PORTAL	FOOTHILL	15.85	.45			16.30	48.34
TESLA PORTAL	SAN JOAQUIN		47.51			47.51	96.35
IRVINGTON PORTAL	COAST RANGE	28.64	.59			29.23	125.58
PULGAS E. PORTAL	BAY CROSSING		21.24			21.24	146.82
CRYSTAL SPRGS. RES.	PENINSULA	1.71			0.18	1.89	148.71
TOTAL		76.68	71.28	0.57	0.18	148.71	

SCALE OF MILES

NOTE: THIS PLATE IS A PORTION OF A MAP BY THE SAN FRANCISCO PUBLIC UTILITIES COMMISSION, "SAN FRANCISCO WATER AND POWER SYSTEMS, GENERAL MAP, 1978".

GENERAL MAP OF HETCH HETCHY WATER AND POWER SYSTEM IN 1978

BOOKMAN—EDMONSTON ENGINEERING, INC.
SACRAMENTO, CALIFORNIA

OCTOBER 1980

In addition to the foregoing facilities, the City of San Francisco participated in the cost of New Don Pedro Dam and Reservoir and has rights to store up to 570,000 acre-feet plus 50 percent of the permissible seasonal encroachment into the flood control pool for a maximum of 170,000 acre-feet. Use of this storage is controlled by an agreement between the City and the Modesto and Turlock Irrigation Districts which own and operate Don Pedro Reservoir.

Water for the Hetch Hetchy Aqueduct is normally released from Hetch Hetchy Reservoir through the Canyon Tunnel and Kirkwood Power House where, for quality control, it is diverted around Early Intake Diversion Dam into Mountain Tunnel. Water can also be diverted into Mountain Tunnel from the Early Intake Reservoir. From Early Intake water is conveyed to Priest Regulating Reservoir and through Moccasin Power House and then into the Foothill Tunnel and pipelines across the San Joaquin Valley.

Water released from Lake Lloyd through the Cherry Power Tunnel and Holm Power House is discharged into the Cherry River at an elevation below Early Intake Diversion Dam. However, water from Lake Lloyd and Lake Eleanor can be conveyed to Early Intake Diversion Dam and into Mountain Tunnel in natural channels and diverted into the Lower Cherry Aqueduct upstream from Holm Power House. This manner of operation does not, of course, permit power generation at Holm Power House and the water mixes with other inflow above Early Intake Diversion Dam.

The Lower Cherry Aqueduct, which was constructed principally to supply the Early Intake Power House and produce electric energy for construction of O'Shaughnessy Dam and other facilities, is no longer in regular use as the Power House has been retired from service. The Aqueduct has a connection to Early Intake Reservoir and thence into Mountain Tunnel and was used during 1977 to supplement water released from Hetch Hetchy Reservoir through Kirkwood Power House. Although the 3.8 mile-long Lower Cherry Aqueduct has a design capacity of 200 second-feet it would be necessary to rehabilitate some reaches to convey the design amount. The operation studies revealed that regular use of the Aqueduct, or an alternative thereto, would be required when the total demand by the Hetch Hetchy System reaches 400 mgd and at that time fishery releases at Moccasin would also need to be supplied from Cherry River. The Aqueduct should be rehabilitated with capacity for 230 cubic-feet per second, including 30 cfs to supply the Moccasin Fish Hatchery. (As previously discussed, the Hatchery supply was set at 30 mgd (46 cfs) in the operation studies.)

Operation Criteria and Constraints

Estimates of the yield of the Hetch Hetchy facilities are dependent on established limitations in the Federal Raker Act, which provided development rights-of-way, in agreements with Modesto and Turlock Irrigation Districts, and in fishery flows.

The Raker Act granted land rights-of-way for the Hetch Hetchy facilities in Yosemite National Park and in the Stanislaus National Forest. The Act requires, among other things, that

prior downstream water rights be satisfied before water is stored by Hetch Hetchy facilities. The prior rights are related to full natural flow in the Tuolumne River at La Grange. Modesto and Turlock Irrigation Districts are entitled to the full natural flows up to 2,350 second-feet during the June 15 to April 14 period and up to 4,000 second-feet during the April 15 to June 14 spring runoff period. In addition, the Modesto Irrigation District is entitled throughout the year to 66 second-feet of the rights of the former Waterford Irrigation District which is now served by Modesto Irrigation District. The full natural flow of the Tuolumne River as used in this study was provided by the staff of Hetch Hetchy Water and Power. It is understood that the values are determined in accordance with procedures satisfactory to the Districts and also to the California Department of Water Resources.

The City and the Districts have entered into agreements regarding the operation of their facilities. The so-called "Fourth Agreement" provides for financial and storage participation by the City in the construction of New Don Pedro Dam and Reservoir in the amounts described in the preceding section. The City is allowed to store natural flows in excess of the amounts defined by Raker Act in its storage space in Don Pedro Reservoir and during other times store and/or divert full natural runoff upstream of Don Pedro Reservoir, to which the Irrigation Districts are otherwise entitled, to the extent that its water stored in Don Pedro Reservoir can satisfy the Districts' rights. A banking

procedure with credits and debits has been established by the City and the Districts. The Districts have sole discretion in the use of water after it is stored in Don Pedro and the City has sole discretion in upstream operation as long as it has "credits" in the Water Bank Account. The City, with the prior consent of the Districts, can have a temporary debit in the Water Bank Account which must be restored as soon as practicable. This temporary debit provision was not used in this study. Copies of the Fourth Agreement and the Instructions For Water Bank Accounting are included in Part 4 of the Appendix.

Reservoir releases for downstream fisheries are established for Hetch Hetchy, Lake Eleanor and Lake Lloyd Reservoirs. The following amounts were reflected in the water yield studies.

Tuolumne River below Hetch Hetchy Reservoir	35 cfs	Sept. 16 to Apr. 30
	75 cfs	May 1 to Sept. 15
Tuolumne River below Early Intake Dam	35 cfs	Sept. 16 to Apr. 30
	75 cfs	May 1 to Sept. 15
Eleanor Creek below Lake Eleanor	5 cfs	Oct. 1 to June 30
	15.5 cfs	July 1 to Sept. 30
Cherry River below Lake Lloyd	5 cfs	Oct. 1 to June 30
	15 cfs	July 1 to Sept. 30
Cherry River below Eleanor Creek	10 cfs	Oct. 1 to June 30
	30 cfs	July 1 to Sept. 30

In addition to the foregoing stipulated amounts of water for fisheries, water is provided at the request of the California Department of Fish and Game for the fish hatchery below Moccasin Dam. An average supply of 30 mgd (46 cfs) is presently provided. (See note in Chapter 1, "Scope".) The Deputy

General Manager and Chief Engineer of the Public Utilities Commission stated that that quantity should be included in estimates of firm water yield in all but critical water years when the amount could be reduced to 15 mgd. Since water must be released to Don Pedro Reservoir for downstream water rights in critical years, provision of 30 mgd does not control in developing firm yield. However, capacity for the fish releases must be available in the Mountain Tunnel to deliver water for the hatchery and when the export demand is at 400 mgd the total tunnel capacity would need to be about 670 cfs. Some uncertainty regarding the Tunnel capacity has been expressed by the Hetch Hetchy staff. Its actual capacity should be ascertained prior to the time when the hatchery and export needs reach the design capacity.

In conjunction with rights of way terms, the City is not permitted to divert the runoff into the Tuolumne River from the 29-square mile drainage area between O'Shaughnessy Dam and Early Intake Dam. There is not any similar restriction regarding the inflow from the 32-square mile drainage between Lakes Eleanor and Lloyd and the Lower Cherry Diversion Dam.

Flood control operating criteria for Don Pedro Reservoir affect the use of storage for the Water Bank Account. The City has rights to use up to 50 percent of the flood pool for conservation storage during times when it is not required for its primary purpose. Each fall the flood pool must be emptied by October 7 and any remaining credits of water stored in the flood control pool are lost at that time.

The water yield studies were made on the assumption that water supply is primary and hydroelectric generation is secondary. These priorities would be most important in the drier water years. Some modifications to existing facilities could be made to minimize the effects on power generation.

Operation Study Procedures

Estimates of future yields of watersheds must be based on assumptions regarding precipitation and runoff because proven forecast methods are not available. Since the water supply record for the Tuolumne River extends back more than 80 years to 1896-97, it can be assumed that dry periods similar to those which have occurred represent extreme conditions which are an adequate basis for yield estimates. The seven-year 1928-34 period is the longest recorded dry period in northern California and the 1975-77 period includes two of the driest winters of record. The California Department of Water Resources estimates that the frequency of occurrence of two such years in sequence is about 1 in 200. Estimates of the safe yield of the Hetch Hetchy System were based on operation during repetition of the two dry periods. The estimated seasonal natural unimparied run-off of the Tuolumne River at La Grange since 1896-97 is shown on Plate 2, "Estimated Seasonal Natural Runoff of Tuolumne River at La Grange". The seasonal periods are water years from October 1 to September 30.

Calendar years during the 1921-78 period were also analyzed for both water operation and power generation to

ESTIMATED SEASONAL NATURAL RUNOFF
OF TUOLUMNE RIVER AT LA GRANGE

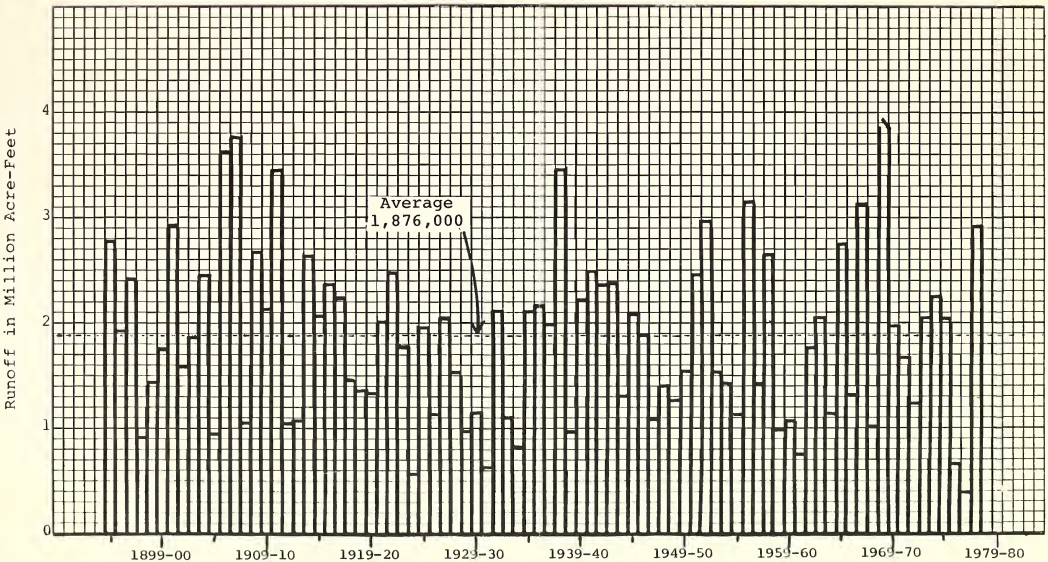


PLATE 2

determine water yields and incidental energy generation. These analyses provided the methodology to evaluate both water and power yield, but since power yield was not optimized in these studies it is not specifically reported. It is, however, shown in the program printout in the appendix.

The period beginning in 1921 includes a full range of year types and is also the period used by the California Deparmtent of Water Resources and the U. S. Water and Power Resources Service. Comparison of study results, if that is later necessary, can be more readily made by using the same period of analyses. The years prior to 1921 were examined for any extreme variations of signficance to the water and power yields and none were found.

Operation studies of the Hetch Hetchy facilities were first made for the two dry periods on a monthly basis using standard manual computation procedures. These studies were confirmed and expanded to include the record from 1921 through 1978 by a computer program. Both studies were based on the previously described criteria. Full description of the studies and results are included in the appendix to this report.

An operation study is basically an accounting procedure for water supplies, uses, diversions, and returns. The accounting in this instance was made on a monthly basis. It was not necessary to examine daily flows in evaluating water supplies, but it may be desirable to do so for power operations.

The accounting steps were set up to reflect the schematic arrangement of facilities and conditions shown on

Plate 3, "Schematic Diagram of Hetch Hetchy System". Additional data and constraints are described in the appendix. The manual studies, which basically involve addition and subtraction of quantities of water, provided a test of the procedures and operation concepts, as well as criteria for performing certain operations to determine the amount of water which the facilities would yield.

To avoid the laborious calculations and risk of errors which would be involved in studies of many years under various assumptions for operating criteria and conditions, it is necessary to utilize a computer program. For this investigation, a general purpose program developed by the Hydrologic Engineering Center of the Corps of Engineers was used. This program, called HEC-5, was designed for river basin analysis with emphasis on flood control and multipurpose reservoir operation.

The complexity of the Hetch Hetchy System with its interelated reservoirs and aqueducts, locations of power plants, and the Don Pedro water bank concept, exceeded the capability of the HEC-5 program as it was available. Development of special routines to make the HEC-5 program respond automatically to operation for all aspects of the Hetch Hetchy System were explored with the assistance of the Hydrologic Engineering Center. It was concluded, however, alternative approaches in data input procedures as described in the appendix would be more effective than would be the time and expense of developing the special routines for HEC-5 The results of this effort is a set of instructions which make the

HEC-5 program properly respond to the operating conditions for the Hetch Hetchy System for both water and power development, although for some purposes the process may require managing input data rather than automatic resolution by the program.

Additional studies of the operation of the Hetch Hetchy System can be made on a monthly or daily basis for various objectives by changing the options which define the system and operating criteria and/or the monthly or daily data input. This will be particularly important in studies of power yields prior to full development of a diversion demand of 400 mgd and also for additional power features. The program is a high speed means of calculating answers to different postulated conditions and the results should be used to guide decisions. As experience is gained by operators familiar with the System and the program input and results, abbreviated studies of certain operation aspects will suffice in making decisions regarding daily operation plans for power as well as for water supplies.

Operation Study Results

Summary results of the studies are shown in Table 1 and on Plates 4 and 5 for the 1928-34 and 1975-77 dry periods, respectively. Results for 1935 and 1978 are also shown to depict post-drought recoveries. Data for 1938 and 1946 are also shown on Table 1 to indicate conditions for a wet and a normal year, respectively. In 1938 the estimated natural runoff was 185 percent of the long-term average and 1946 had average runoff. Each year was preceded by a nearly normal water supply year.

Table 1

SUMMARY OF ANNUAL WATER SUPPLIES AT SELECTED SITES ON THE HETCH HETCHY SYSTEM
WITH REPEAT OF WATER CONDITIONS IN 1928-35, 1938, 1946 AND 1975-78 FOR EXPORT OF 400 MGD (448,000 ACRE-FEET)
AND 34,000 ACRE-FEET FOR MOCCASIN HATCHERY

(In 1,000 Acre-Feet)

	1928	1929	1930	1931	1932	1933	1934	1935	1938	1946	1975	1976	1977	1978
Diversion From Lake Eleanor to Lake Lloyd	0	0	9	41	57	33	54	85	0	0	0	9	56	47
Release From Lake Eleanor to Eleanor Creek	132	106	111	35	124	84	28	112	227	149	166	48	5	168
Diversion From Lake Lloyd to Cherry Power Tunnel	143	103	138	184	81	160	185	158	233	180	151	33	54	108
Release From Lake Lloyd to Cherry Creek	80	56	133	90	128	137	85	179	196	103	155	193	172	195
Inflow to Cherry River Between Lower Cherry Diversion Dam and Lakes Lloyd and Eleanor	148	85	106	76	132	72	67	148	139	42	25	2	2	42
Water Supply at Lower Cherry Diversion Dam	360	247	350	201	384	293	180	439	562	294	346	243	179	405
1/ Diversion Through Lower Cherry Aqueduct to Early Intake	123	125	126	101	118	112	118	136	152	133	135	178	157	178
Diversion From Hetch Hetchy Reservoir Through Canyon Power Tunnel	447	415	411	397	447	463	481	461	493	495	470	305	325	399
Supply Available for Diversion at Early Intake	570	540	537	498	565	575	599	597	645	628	605	483	482	577

1/ Includes about 11,000 acre-feet per year of excess releases from Lake Lloyd and Eleanor for the Moccasin Fish Hatchery. See paranthetic note in Scope on page I-3.

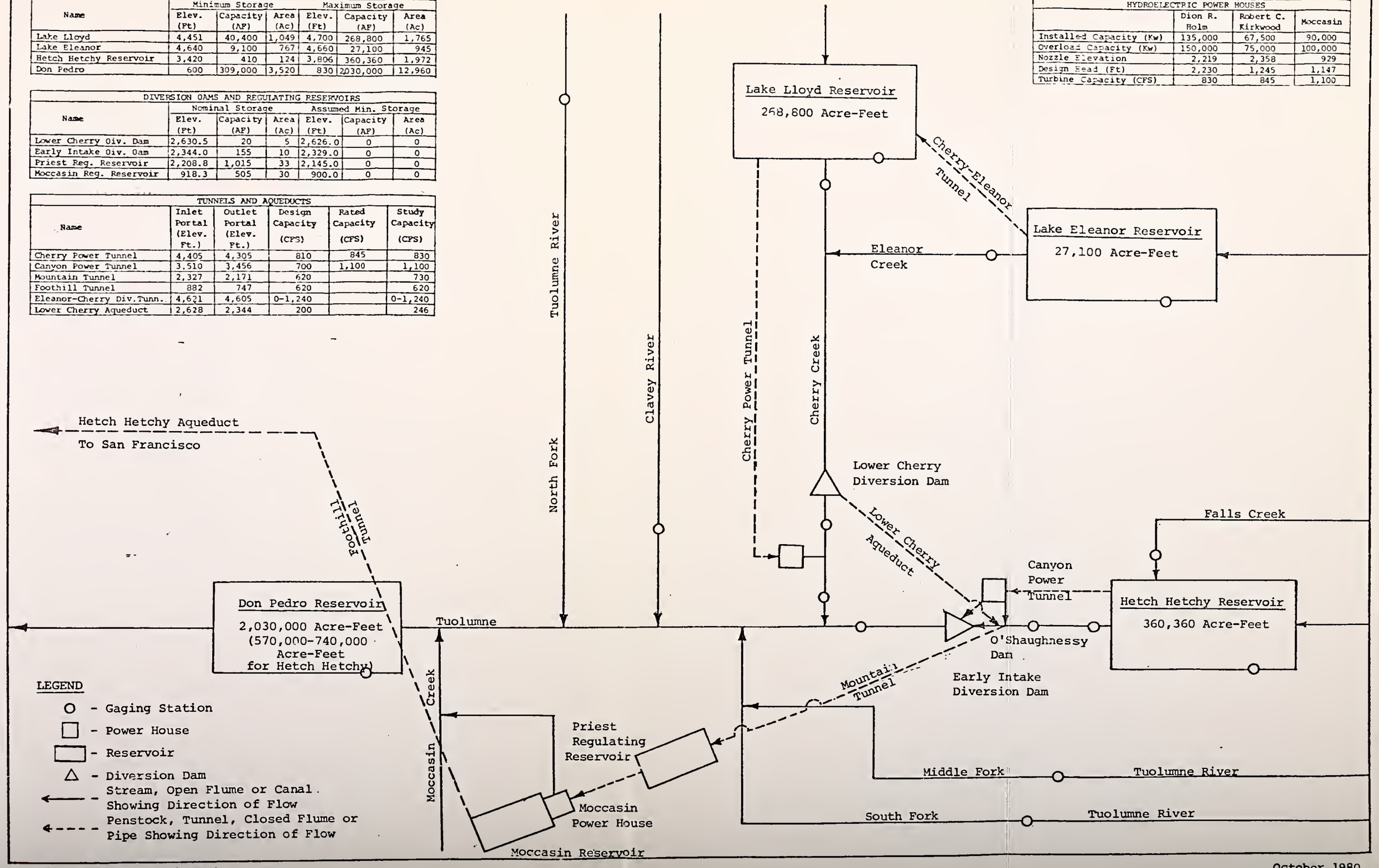
SCHEMATIC DIAGRAM OF HETCH HETCHY SYSTEM

STORAGE RESERVOIRS						
Name	Minimum Storage			Maximum Storage		
	Elev. (Ft)	Capacity (AF)	Area (Ac)	Elev. (Ft)	Capacity (AF)	Area (Ac)
Lake Lloyd	4,451	40,400	1,049	4,700	268,800	1,765
Lake Eleanor	4,640	9,100	767	4,660	27,100	945
Hetch Hetchy Reservoir	3,420	410	124	3,806	360,360	1,972
Don Pedro	600	309,000	3,520	830	2,030,000	12,960

DIVERSION DAMS AND REGULATING RESERVOIRS						
Name	Nominal Storage			Assumed Min. Storage		
	Elev. (Ft)	Capacity (AF)	Area (Ac)	Elev. (Ft)	Capacity (AF)	Area (Ac)
Lower Cherry Div. Dam	2,630.5	20	5	2,626.0	0	0
Early Intake Div. Dam	2,344.0	155	10	2,329.0	0	0
Priest Reg. Reservoir	2,208.8	1,015	33	2,145.0	0	0
Moccasin Reg. Reservoir	918.3	505	30	900.0	0	0

TUNNELS AND AQUEDUCTS					
Name	Inlet Portal (Elev. Ft.)	Outlet Portal (Elev. Ft.)	Design Capacity (CFS)	Rated Capacity (CFS)	Study Capacity (CFS)
Cherry Power Tunnel	4,405	4,305	810	845	830
Canyon Power Tunnel	3,510	3,456	700	1,100	1,100
Mountain Tunnel	2,327	2,171	620		730
Foothill Tunnel	882	747	620		620
Eleanor-Cherry Div.Tunn.	4,621	4,605	0-1,240		0-1,240
Lower Cherry Aqueduct	2,628	2,344	200		246

HYDROELECTRIC POWER HOUSES			
	Dion R. Holm	Robert C. Kirkwood	Moccasin
Installed Capacity (Kw)	135,000	67,500	90,000
Overload Capacity (Kw)	150,000	75,000	100,000
Nozzle Elevation	2,219	2,358	929
Design Head (Ft)	2,230	1,245	1,147
Turbine Capacity (CFS)	830	845	1,100



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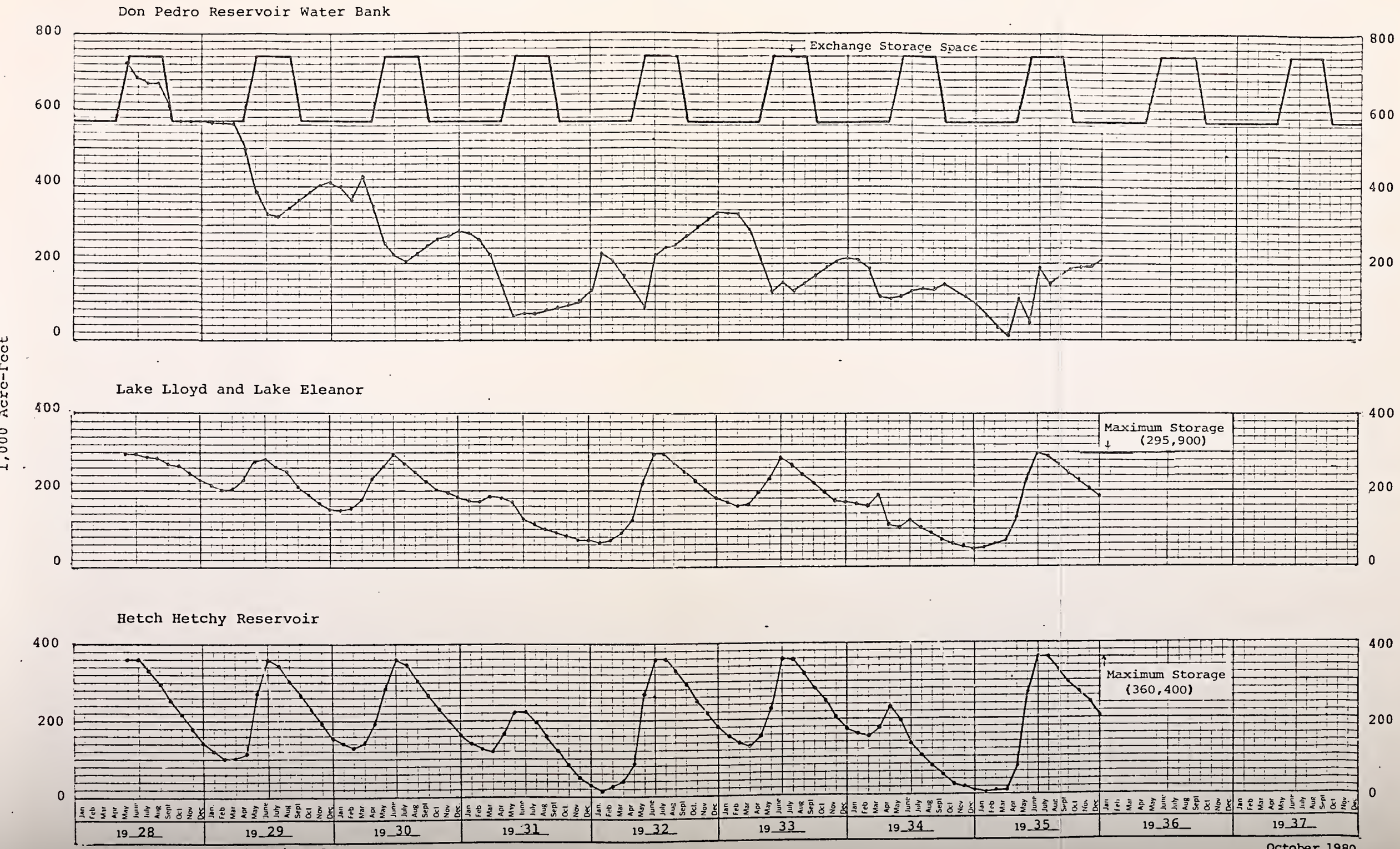
October 1980.

HETCH HETCHY WATER STORAGE CONDITIONS
WITH REPEAT OF 1928-35 WATER SUPPLY AND DIVERSION OF 400 MGD



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October 1980

HETCH HETCHY WATER STORAGE CONDITIONS WITH REPEAT OF 1975-78 WATER SUPPLY AND DIVERSION OF 400 MGD

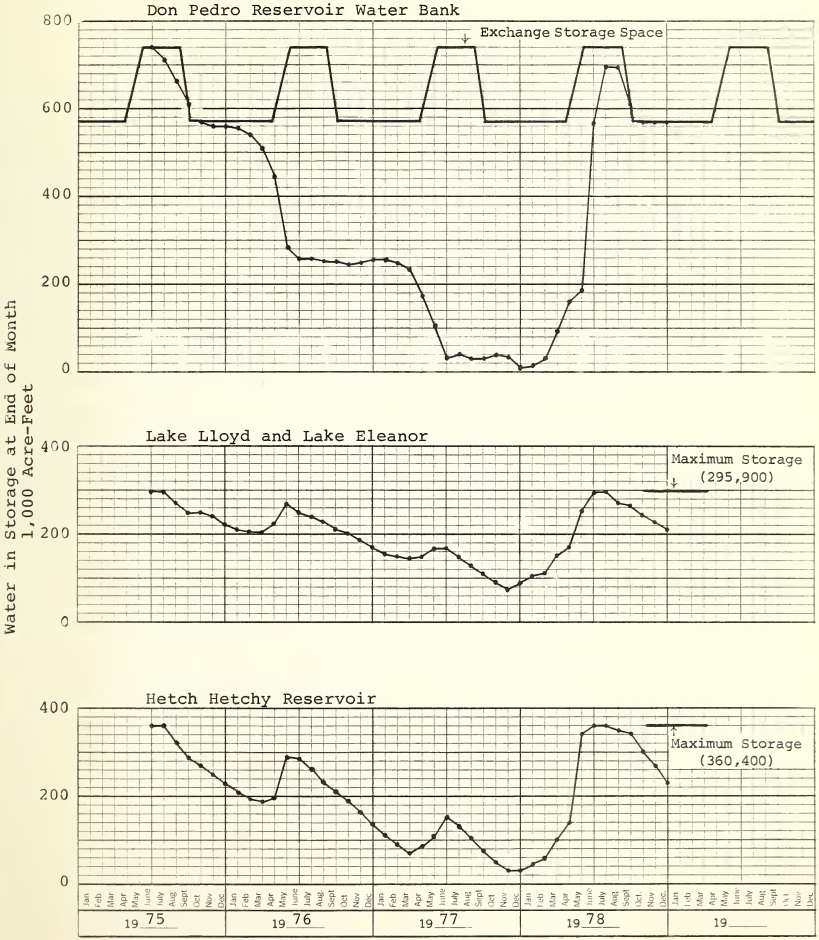

Table 1 shows the annual quantities of water at various locations in the "up country" system and the plates show end-of-month storage conditions. The supply available for Mountain Tunnel at Early Intake is assumed to be deliverable through Moccasin Power House and Foothill Tunnel to Oakdale Portal without significant losses. If future flow measurements reveal significant tunnel losses the supply at Early Intake would need to be increased accordingly. Based on design capacity the facilities would be able to provide up to about 45,000 acre-feet more than the planned 400 mgd export and 30 mgd for the Moccasin Fish Hatchery. (See note in Chapter 1, "Scope".)

The supply available at Early Intake for diversion into Mountain Tunnel includes 30 mgd (about 34,000 acre-feet) for the Moccasin Fish Hatchery. This non-obligatory supply could be safely reduced to 50 percent in dry years, according to Hetch Hetchy System management. Since water releases from "up country" storage were necessary to meet Raker Act deliveries to Don Pedro Reservoir, the Hatchery supplies were not reduced in these studies. This type of operation does not affect power production at Holm Power House in most years since there is sufficient inflow to Cherry River between Lower Cherry Diversion Dam and Lakes Lloyd and Eleanor. In 1976 and 1977, however, inflow from this area was very low and a full supply for the Hatchery would cause a loss of power production at Holm.

Table 1 reveals that it would not be possible to obtain a full supply of 400 mgd (448,000 acre-feet) plus Moccasin

Fish Hatchery water from Hetch Hetchy Reservoir alone in any year during 1929-34 and during 1976-77. The Hetch Hetchy Reservoir supply would be about 397,000 acre-feet in a year like 1931 and 305,000 and 325,000 acre-feet in 1976 and 1977, respectively. The balance of the supply would be diverted through the Lower Cherry Aqueduct and consist primarily of releases from Lakes Eleanor and Lloyd in dry years in amounts shown in Table 1.

The water supply from Lake Lloyd through Cherry Power Tunnel to Holm Power House during dry years would be greatly curtailed. With the present facilities it is not possible to move water from Holm Power House tailrace to Early Intake and therefore it must be released from Lakes Lloyd and Eleanor into natural channels to be diverted into Lower Cherry Aqueduct. An alternative means of partial power recovery is discussed subsequently.

Attention is directed to results in Table 1 for 1938, a wet year, and 1946, an average year, both of which were preceded by above average years. Even under these conditions, it would be necessary to divert water from Lakes Lloyd and Eleanor to Early Intake to retain sufficient storage in Hetch Hetchy Reservoir as a reserve for a possible succeeding dry year(s). Although the total diversion through the Canyon Power Tunnel in years like 1938 and 1946 exceeded 482,000 acre-feet, the amount needed for diversion into the Aqueduct and the Moccasin

Fish Hatchery, some of this supply was available only during the spring and early summer runoff period and at times exceeded the capacity of the Mountain Tunnel.

To provide the needed releases out of Hetch Hetchy Reservoir in years like 1976-77 it would be necessary to begin diverting water from Lakes Lloyd and Eleanor in January, if Hetch Hetchy Reservoir storage is at or below 200,000 acre-feet at the end of December. As the winter water supply becomes known and runoff forecasts can be made for the Hetch Hetchy Reservoir, the rate of diversion can be reduced. It would be necessary, however, to again increase diversions through the Lower Cherry Aqueduct in late summer and fall of all years to provide sufficient carryover storage in Hetch Hetchy Reservoir.

The reservoir storage conditions, shown on Plates 4 and 5, reveal that active storage in all reservoirs and the Don Pedro water bank were nearly expended in the two droughts. By the end of March 1935 and again at end of 1977 the water bank was down to about 10,000 acre-feet. The total active storage in the upper reservoirs amounted to only about 30,000 acre-feet at the end of March 1935 and about 70,000 acre-feet at the end of 1977. (Inactive storage in the upper reservoir is about 50,000 acre-feet.) Under these conditions, the reserve would be about 4 percent and eight percent of total storage for the respective drought periods or less than a one-month supply at the end of the 1928-34 dry period.

Table 2

ANNUAL WATER SUPPLY FROM HETCH HETCHY RESERVOIR
AND LAKES LLOYD AND ELEANOR WITH 400 MGD (448,000 ACRE-FEET)
AQUEDUCT DIVERSION AND 34,000 ACRE-FEET FOR MOCCASIN FISH HATCHERY

(1,000 Acre-Feet)

Year	Hetch Hetchy Reservoir	Lakes Lloyd And Eleanor	Year	Hetch Hetchy Reservoir	Lakes Lloyd And Eleanor
1922	394	88	1951	432	50
1923	398	84	1952	377	105
1924	410	72	1953	409	73
1925	394	88	1954	387	95
1926	398	84	1955	390	92
1927	391	91	1956	413	69
1928	393	89	1957	392	90
1929	400	82	1958	409	73
1930	386	96	1959	420	62
1931	367	115	1960	427	55
1932	395	87	1961	436	46
1933	438	44	1962	423	59
1934	481	1	1963	421	61
1935	417	65	1964	421	61
1936	389	93	1965	421	61
1937	389	93	1966	428	54
1938	397	85	1967	416	66
1939	418	64	1968	429	53
1940	415	67	1969	408	74
1941	429	53	1970	420	62
1942	398	84	1971	424	58
1943	407	75	1972	428	54
1944	410	72	1973	419	63
1945	402	80	1974	442	40
1946	417	65	1975	417	65
1947	409	73	1976	305	177
1948	418	64	1977	325	157
1949	417	65	1978	346	136
1950	416	66			

Table 2 summarizes the annual quantities of water which would need to be provided from Hetch Hetchy Reservoir and from Lakes Lloyd and Eleanor through a water supply period like 1922 to 1978 to meet aqueduct and fish hatchery needs. Table 2 reveals that it would not be possible to obtain a full supply of 400 mgd (448,000 acre-feet) plus Moccasin Fish Hatchery water from Hetch Hetchy Reservoir alone in any year during the period of analysis. This is true even during years with high runoff since a reserve of 200,000 acre-feet must be provided by the end of December in the event the following year is critically dry. For example, in 1934 downstream demands on Cherry Creek and Eleanor Creek prevented significant diversion from these sources and it was necessary to divert from the Hetch Hetchy reserve.

It should be recognized that there can be some variation in the relative deliveries from Hetch Hetchy Reservoir and Lakes Lloyd and Eleanor as shown in Table 2. The analyses were based on operation of the facilities for water supply and in years when there would be spills from Lakes Eleanor and/or Lloyd, these flows were used instead of reducing storage in Hetch Hetchy Reservoir. Studies of power and water development would indicate the amount of additional water which could be released from Hetch Hetchy Reservoir for power while retaining sufficient carryover storage for water supply.

Comparison of Yield of Present Facilities With Freeman Study in 1912

When the Freeman study was made in 1912 it was concluded that a full supply of 620 second-feet (400 mgd) with a safe margin could be obtained from Hetch Hetchy Reservoir, Lake Lloyd and Lake Eleanor. At that time, it was proposed the water would be diverted from Cherry Reservoir (Lake Lloyd) into Eleanor Reservoir and then into Hetch Hetchy Reservoir. Cherry Reservoir would store 104,000 acre-feet. Hetch Hetchy Reservoir was proposed to store about 340,000 acre-feet. Actual present storage is 286,800, 27,100 and 360,360 acre-feet, respectively, for Lake Lloyd, Lake Eleanor and Hetch Hetchy Reservoir.

The Freeman study was based on water supply data for the 1896-1911 period. In that period, there were two isolated dry years (1898 and 1908) generally comparable to dry years in the 1928-34 period except for 1931 which was much drier. Annual runoff in 1976 and 1977 was only about half of the runoff in 1898 and 1908.

The Freeman study did not include as much water for downstream rights as was later required by the Raker Act. For low runoff years of comparable wetness, the present entitlement would be 913,000 acre-feet as compared to 471,000 acre-feet used in the Freeman study.

Provision for fishery releases from storage reservoirs was not included in the Freeman study. These requirements total about 41,000 acre-feet annually under present conditions.

In summary, drier years, greater downstream rights and fishery releases would not permit diversion of 400 mgd from the three upper reservoirs as contemplated by the Freeman study. It is possible to do so, however, with somewhat greater storage capacity in the three upper reservoirs (656,000 acre-feet vs. 509,000 acre-feet) coupled with water bank storage in Don Pedro Reservoir (570,000 acre-feet minimum plus 170,000 acre-feet seasonal use of flood control space).

Optimizing Water and Power Yields

The analyses of the water yield of present facilities were made on the basis of priority of water supply over power production. The principal adverse impact on power production is the reduction in generation at Holm Power House resulting from the need to release water from Lake Lloyd into Cherry Creek for diversion into the Lower Cherry Aqueduct. Some of the energy could be salvaged, however, by constructing a pumping plant at Holm Power House to pump water into the Lower Cherry Aqueduct. The pumping lift would be about 400 feet while the head on the Holm Power House would be in the range of 2,370 feet assuming average depth of storage in Lake Lloyd (4,577 feet msl). There would be a net advantage in the order of 1,900 feet of head depending on friction losses. The value of the salvaged energy would need to be compared with the amortization and other costs of a pumping plant. Use of a pumping plant would be limited with present demands on the Hetch Hetchy Aqueduct but would increase

as the demand on the Aqueduct increases from present levels to a full 400 mgd. This aspect would need to be evaluated in estimating when a pumping plant would be justified.

A secondary benefit of a pumping plant would be occassional pumping to utilize the full capacity of the Mountain Tunnel and Moccasin Power House. The tunnel has a capacity of 730 second-feet while the capacity needed for 400 mgd export and Moccasin Fish Hatchery supply is nearly 670 second-feet. Prior to the need to export the full 400 mgd, there could be a greater amount of unrequired capacity. When the water supply from Hetch Hetchy Reservoir is insufficient to fill the Mountain Tunnel, water could be pumped from the discharge of Holm Power House into the Lower Cherry Aqueduct and delivered to Early Intake. The pumping lift at Holm Power House, 400 feet, would be more than offset by the 1,147 feet of head for power generation at Moccasin Power House.

Two factors which would limit the foregoing pumping-generating alternative are: (1) the quality of water diverted from the Cherry River is less certain than that of the Hetch Hetchy Basin and (2) any future development of the power head between Holm Power House and Don Pedro Reservoir. Since a pumping plant and rehabilitation of the Lower Cherry Aqueduct could be completed in much less time than development of the Holm to Don Pedro head, it may be financially feasible to proceed with such a project in advance of the time it is needed to provide for the full Hetch Hetchy Aquduct water supply.

Enlargement of Hetch Hetchy Reservoir

An alternative to diverting water from the Cherry Reservoir through the Lower Cherry Aqueduct to firm up Hetch Hetchy Reservoir releases would be to enlarge the carryover storage capability of the Reservoir. This would (1) save pumping energy, (2) increase the average head on Kirkwood Power House and increase capacity and energy output and (3) increase the certainty of the quality of water delivered from the Hetch Hetchy Aqueduct. A study was made to determine the amount of storage which would be necessary for both the 1928-34 and 1975-77 dry periods.

The average flow of the Tuolumne River into Hetch Hetchy Reservoir is sufficient to provide 400 mgd (448,000 acre-feet) plus present fishery releases to the river. The present storage capacity of about 360,000 acre-feet is adequate to provide an average of only about 315,000 acre-feet annually during a critical period like August 1975 through November 1977. Since 15 cfs or about 11,000 acre-feet would be used in the Moccasin Fish Hatchery in similar dry years the divertable yield would be about 304,000 acre-feet.

Operation studies of Hetch Hetchy Reserovir as a sole source in the upper basin in conjunction with the water bank in Don Pedro Reservoir and other established operations criteria indicate that it would be necessary to have 700,000 acre-feet of storage to provide 400 mgd without any deficiencies. This

would require raising O'Shaughnessy Dam about 160 feet from 312 feet to around 470 feet above streambed.

Study was also given to raising the storage level 50 feet which would avoid flooding structures near the dam. This increase would provide about 100,000 acre-feet of additional storage and increase the safe divertable yield from about 304,000 acre-feet to about 348,000 acre-feet.

An intermediate storage of 600,000 acre-feet was also evaluated. This would involve an increase in storage level by about 120 feet. The increase in firm yield would be about 106,000 acre-feet annually for a total divertable yield of 410,000 acre-feet. This yield would occur in a critical period like August 1975 through November 1977. The yield during such a critical period would have deficiency of about 8 percent in relation to 400 mgd or 448,000 acre-feet annually.

CHAPTER III. CONCLUSIONS

Based on the studies summarized in this report and the supporting information in the appendix, the following conclusions can be made:

1. A firm yield of 400 mgd (448,000 acre-feet per year) can be developed without deficiencies with existing facilities of the Hetch Hetchy System and exchange storage space in Don Pedro Reservoir with water supplies comparable to the dry periods of record. A yield of 400 mgd is dependent on various conditions principal of which are (a) the facilities would be operated primarily for water supply and power development would be secondary and (b) it would be necessary to have capability to divert up to 230 cubic-feet per second from the Cherry River to Early Intake through a rehabilitated Lower Cherry Aqueduct or alternative facilities.

2. Some of the water supply operating criteria used in the study can be refined to improve the water supply available for power generation and still maintain a firm yield of 400 mgd.

3. The computer program utilized in this study can be used for daily power and water operations and for longer term planning by revising the options which

define operation criteria and by using daily input data. As experience is gained in use of the program and the relative effects of modifications become apparent, it will be possible to utilize portions of the program to develop sufficient information for operation decisions.

4. There is sufficient runoff into Hetch Hetchy Reservoir to provide a firm yield of 400 mgd and water for the Moccasin Fish Hatchery, without reliance on storage in Lakes Lloyd and Eleanor, provided the storage capacity of the Reservoir is enlarged. To increase the present divertable firm yield from about 304,000 acre-feet to 448,000 acre-feet per year (400 mgd), and to provide 15 cubic-feet per second (11,000 acre-feet per year) for the Moccasin Fish Hatchery in dry years would require increasing the Reservoir capacity from 360,000 acre-feet to 700,000 acre-feet by raising O' Shaughnessy Dam from 312 feet to about 470 feet above streambed.

5. A nominal 50-feet increase in the height of O'Shaughnessy Dam, which would not require relocation or protection of operating structures, would provide about 100,000 acre-feet of additional storage and increase the annual firm divertable yield by about 44,000 acre-feet to a total of 348,000 acre-feet or 100,000 acre-feet less than a full supply.

6. If the capacity of Hetch Hetchy Reservoir is increased to 600,000 acre-feet by raising O'Shaughnessy Dam by about 160 feet, the annual divertable firm yield would be about 410,000 acre-feet or about 8 percent less than a full supply in years like 1976 and 1977.